Comment on "Design of a broadband highly dispersive pure silica photonic crystal fiber" by Subbaraman *et al.*

Niels Asger Mortensen

MIC – Department of Micro and Nanotechnology,

NanoDTU, Technical University of Denmark,

*bld. 345 east, DK-2800 Kongens Lyngby, Denmark**

In a recent paper, Subbaraman *et al.* report a theoretical and numerical study of highly dispersive pure silica photonic crystal fiber supporting group-velocity dispersion exceeding -2×10^4 ps/nm/km. This comment argues that the authors only consider one out of the two sides of the same coin, by not taking the corresponding beating length into account.

OCIS codes: 060.2280, 060.4005

*Corresponding author: asger@apsmail.org

In a recent paper, Subbaraman *et al.* report a theoretical and numerical study of highly dispersive pure silica photonic crystal fiber [1]. The photonic crystal fiber has an air-hole structure making the effective index profile resemble that of a dispersion-compensating fiber with a w-profile in the doping. As pointed out by the authors, the negative group-velocity dispersion (GVD) originates from an avoided-crossing of the uncoupled inner and outer modes. The authors employ coupled-mode theory to give quite simple analytical expressions which they confirm numerically by full-wave simulations. While the analytical results are quite elegant and fully correct, the authors are missing an important point in their analysis and physical interpretations. The authors correctly show that the maximal dispersion parameter is inversely proportional to the coupling constant κ, see Eq. (S6),

$$D_{\max} = \mp \frac{\pi}{2c\kappa}\left(\frac{dn_1}{d\lambda} - \frac{dn_2}{d\lambda}\right)^2 \tag{1}$$

but from Eq. (S2) it also straightforwardly follows that the difference in propagation constant at ω_p is

$$\Delta\beta = B_+ - B_- = 2\kappa. \tag{2}$$

In other words, the corresponding beating length (coupling length) between the two supermodes is

$$L_B = 2\pi/|\Delta\beta| = \pi/\kappa. \tag{3}$$

To put things even more clear we may rewrite Eq. (1) in terms of Eq. (3) which gives

$$D_{\max} = \mp \frac{L_B}{2c}\left(\frac{dn_1}{d\lambda} - \frac{dn_2}{d\lambda}\right)^2. \tag{4}$$

Thus, large negative (or positive) group-velocity dispersion inevitably comes at the price of a correspondingly long beating length (corresponding to a small mode spacing).

As pointed out in e.g. Ref. [2] this has strong implications for the loss in general and in the present case for the resulting group-delay of a propagating pulse. Basically, L_B acts as a cut-off in the scattering rates associated with longitudinal index variations. Only slow variations with a characteristic length scale ξ longer than L_B will have a negligible influence on the scattering while faster variations with ξ shorter than L_B may course pronounced scattering loss and intra-modal coupling. Obviously, one should in general aim at a short L_B to minimize scattering loss and intermodal coupling effects [2, 3]. Longitudinal index variations are inevitably present regardless of the fabrication procedure. In addition to

fabrication related issues there will also be effects of microbending which has shown to potentially be a serious source of scattering loss in large-mode area photonic crystal fibers [4]. In fact, even macrobending will deform the index profile slightly and induce scattering loss and intra-modal coupling.

In the present context intra-modal coupling will degrade the effective dispersion compensating of a pulse. Imagine that the pulse is launched in the supermode with the negative GVD, then scattering loss will after a length of the order ξ have redistributed the power equally between the two supermodes. As correctly shown by the authors the two supermodes have dispersion parameter of opposite sign and thus the resulting dispersion compensation is easily washed out and averaged to zero.

Obviously, there exists some window where intra-modal coupling of the supermodes is negligible so that the negative GVD can be utilized for dispersion compensation, but GVDs of the order -2×10^4 ps/nm/km seems well outside the window. To illustrate this it is worthwhile emphasizing existing technology [5]. Practical MCVD fabricated fibers typically operate around -100 to -200 ps/nm/km [5], though more extreme values have been reported [6]. These fibers have been subject to a high degree of optimization, most likely pushing the beating length to the maximal possible with the present fabrication technology. The fabrication of photonic crystal fibers is without any doubt even more challenging and thus it is difficult to envision the realization of the GVD proposed by Subbaraman *et al.* [1]. In fact, increasing the typical GVD by two orders of magnitude would require their photonic crystal fiber to appear absolutely longitudinal uniform on a 100 times longer length than in typical state-of-the-art MCVD fabricated fibers!

References

1. H. Subbaraman, T. Ling, Y. Q. Jiang, M. Y. Chen, P. Y. Cao, and R. T. Chen, “Design of a broadband highly dispersive pure silica photonic crystal fiber,” Appl. Optics **46**, 3263 – 3268 (2007).
2. N. A. Mortensen and J. R. Folkenberg, “Low-loss criterion and effective area considerations for photonic crystal fibres,” J. Opt. A: Pure Appl. Opt. **5**, 163 – 167 (2003).
3. J. D. Love, “Application of a low-loss criterion to optical wave-guides and devices,” IEE Proc. J **136**, 225 – 228 (1989).
4. M. D. Nielsen, N. A. Mortensen, and J. R. Folkenberg, “Reduced microdeformation

attenuation in large-mode-area photonic crystal fibers for visible applications," Opt. Lett. **28**, 1645 – 1647 (2003).

5. L. Grüner-Nielsen, S. N. Knudsen, B. Edvold, T. Veng, D. Magnussen, C. C. Larsen, and H. Damsgaard, "Dispersion compensating fibers," Opt. Fiber Technol. **6**, 164 – 180 (2000).
6. J. L. Auguste, R. Jindal, J.-M. Blondy, M. Clapeau, J. Marcou, B. Dussardier, G. Monnom, D. B. Ostrowsky, B. P. Pal, and K. Thyagarajan, "-1800ps/(nm.km) chromatic dispersion at 1.55 μm in dual concentric core fibre," Electron. Lett. **36**, 1689 – 1691 (2000).